UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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TWIN CITIES MINING RESEARCH CENTER

Walter E. Lewis, Research Director

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MULTIDISCIPLINARY RESEARCH LEADING TO UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Quarterly Status Report
October 1, 1965 to January 1, 1966

BUREAU OF MINES
MINERALS RESEARCH REPORT

Twin Cities Mining Research Center
Minneapolis, Minnesota

Second Quarter, FY 1966

Project Title: Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

Submitted by: Thomas C. Atchison, Senior Research Scientist

Date begun: April 1965 To be completed: March 1968

Personnel: Thomas C. Atchison, Supv. Research Physicist
David E. Fogelson, Research Geophysicist
Oleg Terichow, Min. Meth. Res. Engineer
Clifford W. Schultz, Res. Ext. Metallurgist
Other Bureau personnel, as assigned

PROGRESS REPORT

Objective

To provide the basic scientific and engineering knowledge needed for subsequent development of an extraterrestrial mineral resource extraction, processing, and utilization technology for supporting and enhancing the economy of manned lunar and planetary missions.

Progress During the Second Quarter

Work during the quarter progressed somewhat ahead of the schedule outlined in the July work plan. Specific experimental tasks to be started during the first two years of the program were delineated and some of them begun. A detailed proposal for continuing and extending the work on the program was prepared and presented to NASA. Plans for extending basic rock property measurement work at Minneapolis to include lunar environmental conditions were completed and specifications for ultrahigh vacuum equipment were drawn up.

The accumulation of background information on the nature of extraterrestrial bodies and their environment and the utilization of extraterrestrial resources was continued. Especially helpful were visits to the Lunar Planetary Group at Air Force Cambridge Research Laboratories and the Center for Radiophysics and Space Research at Cornell University. These visits in a sense completed our exposure to the spectrum of thinking on the nature of the lunar surface. A further benefit derived from the laboratory visits of this and the preceding quarter is the fact that we have been able to crystallize our thinking on the problem of adhesion, or perhaps more properly, the interaction between solids in a vacuum. This has resulted in the design

of a series of experiments on this problem area. The experimental devices needed are currently being fabricated in our shops and other components are on order. The experiments planned are:

1. Determination of the free energies and equilibrium constants for adsorption of various gases on silicate surfaces.

2. A study of the ability of surfaces formed in a vacuum to reconsolidate and the time dependence of this effect.

3. Measurement of the coefficient of friction between metal-silicate and silicate-silicate interfaces under lunar vacuum.

Sample preparation work was underway on the simulated lunar materials collected in September, including the development of new techniques for preparing samples from some of the materials not susceptible to our usual methods. Basalt and dacite cores were prepared for use in the rock physics environmental studies. These studies will measure the strength and elastic properties of the rock at several temperatures (from dry ice to superheated steam) and several atmospheres (air, saturated water vapor, dry nitrogen, and moderate vacuum). Samples from six of the rock types were prepared and tested for surface hardness, with the following results:

Rock type	Number of observations	Hardness (Shore sceleroscope units, mean value and standard deviation)
Obsidian	300	103 ± 4
Flow basalt	300	84 ± 4
Dacite	300	80 ± 5
Altered rhyolite	300	54 ± 5
Tuff	300	7 ± 1
Pumice	300	6 ± 1

Similar measurements on a number of rock types studied in connection with mining problems here on Earth are shown for comparison:

Rock type	Number of observations	Hardness (Shore sceleroscope units, mean value and standard deviation)
Charcoal granite	100	91 ± 7
Rockville granite	100	90 ± 7
Dresser basalt	300	86 ± 5
Taconite	100	80 ± 9
Dolomitic limestone	100	37 ± 15
Alabama limestone	100	19 ± 5

Researchers at a number of laboratories working on lunar surface problems have indicated an interest in obtaining samples of our simulated lunar materials, including Jim Fountain at Marshall Space Center, Bruce Hapke at Cornell University, and Jerry Plunkett at Denver University. We plan to provide samples for research related to our program wherever feasible, to aid in correlating results.

Progress in extending basic rock property measurements to the lunar environment is ahead of our original plans. After a number of visits to laboratories using high vacuum equipment and discussions with vacuum equipment manufacturers, we have prepared technical specifications for two vacuum chambers to be used for property measurements and for the experimental work on adhesion problems. Delivery is expected in 60 to 90 days.

In early November a proposal for extending the Bureau's program was presented to NASA's Office of Advanced Research and Technology. The proposal is based on research ideas resulting from the Bureau seminar held last August, and it emphasizes some of the most urgent problem areas in developing a lunar processing technology. The new experimental work proposed is based primarily on the extension of basic research in progress at several of the Bureau's metallurgy research centers. However, a few additional problem areas in mining research are included also.

Schedule of Work for Third and Fourth Quarters

The core group at Minneapolis will continue to obtain and analyze background information applicable to the program and to consider experimental tasks that should be added to the program. However, primary effort during the next two quarters will be on initiating and carrying out the specific experimental tasks listed below. The first group of tasks are those planned under the current contract. Shown are the location of the work, the investigator in charge, the estimated starting date, and a summary of the work to be accomplished. Two of the tasks listed will not begin until next fiscal year but they are included for completeness.

1. Task: Selection and sample collection of simulated lunar materials
   Center: Twin Cities Mining Research Center
   Investigator: David E. Fogelson, Research Geophysicist
   Start: September 1965

Select and obtain samples of rocks and minerals covering the range of materials likely to be encountered on the Moon. This will require consideration of materials which, though they exist on Earth, are not normally studied as a mining or processing problem. Examples might be a flow basalt or a poorly welded tuff. It may also require considering materials that do not exist in a natural form here but may be produced artificially. Examples might be a rock froth obtained by extruding magma into a vacuum or a sputtered surface obtained by ion bombardment in a vacuum.

2. Task: Physical properties of simulated lunar materials
Center: Twin Cities Mining Research Center
Investigator: All projects
Start: October 1965

Incorporate simulated lunar materials into basic fragmentation research currently in progress. By this means determine the composition, elastic, strength, surface, thermal, electrical, magnetic, and explosive shock properties of simulated lunar materials in Earth environment.

3. Task: Chemical reactivity and cold welding of freshly formed surfaces
Center: Twin Cities Mining Research Center
Investigator: Clifford W. Schultz, Research Extractive Metallurgist
Start: January 1966

Study the adsorption of various gases on mineral surfaces during comminution in a vacuum. Measure the desorption of these gases at several temperature levels. From these data calculate the free energy and equilibrium constant for adsorption. Simultaneously, in a separate experiment, study the ability of freshly formed surfaces to reconsolidate or cold weld. If such a phenomenon is observed, study the time dependence of the ability to cold weld.

4. Task: Surface properties of rock in lunar environment
Center: Twin Cities Mining Research Center
Investigator: Oleg Terichow, Mining Methods Research Engineer
Start: March 1966

Extend current experimental studies of surface penetration, friction, abrasion, and surface energy of rocks and minerals to include lunar vacuum and temperature environment by adding commercially available vacuum equipment to present laboratory experiments.

5. Task: Effect of vacuum on explosive properties
Center: Pittsburgh Explosives Research Center
Investigator: J. Edmund Hay, Research Physicist
Start: March 1966

Study the effect of extremely low pressures on explosive properties, especially the role of gas in intergranular voids and how it affects iniation and propagation of the detonation. Investigate the problems of encapsulation of explosives and detonators, particularly leak rates and how they affect long-term storage.

6. Task: Effect of micrometeoroid bombardment on explosives
Center: Pittsburgh Explosives Research Center
Investigator: J. Edmund Hay, Research Physicist
Start: March 1966

Study the sensitivity of selected explosives to multiple impact from small particles such as might occur from micrometeoroid bombardment, using techniques developed in hypervelocity studies already in progress.

7. Task: Explosive blast effects in lunar vacuum and gravity
Center: Pittsburgh Explosives Research Center
Investigator: J. Edmund Hay, Research Physicist
Start: March 1966

Investigate the nature of the blast from an explosive detonation on the Moon by experimentally determining pressure-distance profiles in a vacuum chamber. Determine shock and product velocities over a range of low pressures. Also study the velocity of fragments originating from the material encapsulating the explosive. Determine gravity effects analytically.

8. Task: Strength and elastic properties of rock in lunar environment
Center: Twin Cities Mining Research Center
Investigator: John R. McWilliams, Mining Methods Research Engineer
Start: June 1966

Extend current measurements of static and dynamic elastic moduli and compressive and tensile strengths of rock to include lunar vacuum and temperature environment.

9. Task: Fracture and other failure mechanisms in lunar environment
Center: Twin Cities Mining Research Center
Investigator: John R. McWilliams, Mining Methods Research Engineer
Start: June 1966

Extend current experimental studies of rock failure by such mechanisms as dislocation, twinning, and crack formation to include lunar vacuum and temperature environment.

10. Task: Thermophysical, strength, and elastic properties of rock at elevated temperature in vacuum
Center: Twin Cities Mining Research Center
Investigator: Robert L. Marovelli, Mining Methods Research Engineer
Start: October 1966

Currently the thermophysical, strength, and elastic properties of rock at temperatures up to the melting point are being measured. Investigate the feasibility of extending this work to lunar vacuum environment.

11. Task: Rock vaporization, melting, and thermal spalling mechanisms in vacuum
Center: Twin Cities Mining Research Center
Investigator: Robert L. Marovelli, Mining Methods Research Engineer
Start: October 1966

Investigate the feasibility of extending current thermal fragmentation studies to lunar vacuum environment.

The second group of tasks are those proposed for extending the program. If the new proposal is funded by NASA on the anniversary date of the contract, these tasks will be initiated as soon as possible after April 1, 1966.

1. Task: Volcanism and ore genesis as related to lunar mining
Center: Twin Cities Metallurgy Research Center
Investigator: Rolland L. Blake, Research Geologist

Study the genesis of ore deposits and the occurrence of minerals associated with volcanic activity here on Earth. Study the effects of the lunar environment and other environments on mineralization and ore genesis. Conduct a thorough literature search on the above subject in order to bring together the pertinent information found in the literature and to define those specific areas where additional work is needed.

2. Task: Electrowinning of oxygen from silicate rocks
Center: Reno Metallurgy Research Center
Investigator: Thomas A. Henrie, Research Metallurgist

Investigate the mechanism of anode reactions in the electrolysis of silicates. Parallel to this investigation study current efficiency as a function of melt composition. If suitable current efficiencies are not obtained, develop an anode compatible with melts containing added halides.

3. Task: Reduction of silicates with carbon
Center: Twin Cities Metallurgy Research Center
Investigator: Perry L. Weston, Research Extractive Metallurgist

Study the kinetics and mechanisms of the reactions between carbon and various oxides and silicates in a vacuum environment. Begin this study with single mineral systems and extend ultimately to the more complex multicomponent systems. At all stages of the investigation, determine the relationship between the physical and thermodynamic parameters describing the system and the kinetics of reaction.

4. Task: Magnetic and electrostatic properties of minerals in vacuum
Center: College Park Metallurgy Research Center
Investigator: Foster Fraas, Research Metallurgist

Currently the effect of adsorbed layers on the magnetic and electrostatic properties of minerals is being studied. Extend this work to include

adsorption and contact electrification measurements in a vacuum and their effect on the separability of nonconducting minerals. Place emphasis on the hydrated silicates found in primary igneous rocks.

5. Task: Stability of hydrous silicates and oxides in lunar environment
   Center: Albany Metallurgy Research Center
   Investigator: Hal J. Kelly, Research Ceramic Engineer

Investigate the stability of certain hydrated silicates and oxides by a combination of differential thermal analysis (DTA), thermogravimetric analysis (TGA), and effluent gas analysis (EGA). Such an investigation would serve two purposes: First, it would allow us to estimate the present state of such hydrates as may have been formed on the Moon. Second, it would provide an estimate of the energy requirements for the extraction of water and/or oxygen and an estimate of the rate of reaction. The mineral species to be investigated in the first year would be the mica and amphibole series of minerals associated with primary igneous rocks.

6. Task: Biological production of sulfuric acid
   Center: College Park Metallurgy Research Center
   Investigator: Joseph A. Sutton, Research Chemist

Establish the limiting environmental conditions for the survival of bacteria of the genus thiobacillus. Determine the rate of sulfuric acid production within these limits. Conduct a literature survey and visit such laboratories as may be necessary to establish the state of the art in the use of bacteria in any stage of a life support system in an extraterrestrial environment.

7. Task: Reduction of silicates in plasma torch
   Center: College Park Metallurgy Research Center
   Investigator: Robert T. MacMillan, Research Chemist

Study the feasibility of reducing silicates with activated hydrogen in a plasma torch.

8. Task: Effect of lunar environment on behavior of fine particles
   Center: Spokane Mining Research Laboratory
   Investigator: William R. Wayment, Mining Methods Research Engineer

Extend current studies of fine particle behavior in mine backfill applications to include lunar environment. Measure such properties as density of packing, repose angle, and rate of flow through channels and orifices. Correlate the observed behavior with the quantitative measurements of electrostatic properties obtained at College Park, Md. under task 4.

9. Task: Cuttings removal in drilling in lunar environment
Center: Twin Cities Mining Research Center
Investigator: James Paone, Mining Methods Research Engineer

Investigate various means of removing drill cuttings with or without flushing media in lunar environment.

10. Task: Cooling and lubricating bits in drilling in lunar environment
Center: Twin Cities Mining Research Center
Investigator: James Paone, Mining Methods Research Engineer

Determine problems in heat removal and bit lubrication associated with drilling in lunar environment. Make quantitative analysis of temperatures generated in drilling systems with or without flushing fluids.

11. Task: Support for underground lunar shelter
Center: Spokane Mining Research Laboratory
Investigator: William R. Wayment, Mining Methods Research Engineer

Conduct basic research on the properties of synthetic foams, or other suitable materials, to determine their protective capabilities in lunar environment. Study the load-behavior relationships of an underground lining in lunar environment.